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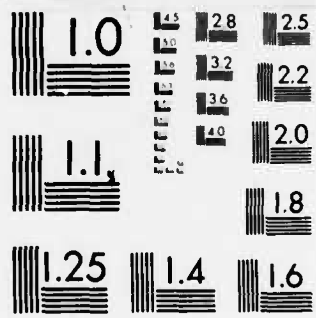

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ANALYSIS OF OBSTACLE NEGOTIATION BY
ARTICULATED TRACKED VEHICLES
THE STATE OF THE ART

by:

Peter M. Brady, Jr.

PREPARED FOR:

David W. Taylor Naval Ship Research and
Development Center
Code 112
Bethesda, MD 20084

Under Contract:

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STEVENS INSTITUTE OF TECHNOLOGY

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OBJECTIVE

The objective of this study was to investigate and recommend an approach which will provide for the assessment of the ability of articulated tracked vehicles to negotiate obstacles and gaps. A further objective was to coordinate these efforts with the articulated vehicle studies currently being conducted by the U. S. Army Corps of Engineers Waterways Experiment Station (WES).

INTRODUCTION

Articulation has been proposed as a means of improving the ground crawling capability of tracked vehicles for many years, notably by Bekker [1] and Nuttall [2] among others. Implementation of this notion in hardware occured within the 1960's as vehicles such as the "Polecats" and "Cobra" were constructed. The U. S. Army built a test bed (CCRV) [3] to assess a controlled powered coupling system for military sized vehicles (M-113 APC's). This vehicle demonstrated significant performance increases over that of the single vehicle.

Concurrently with these hardware developments, the U. S. Army was sponsoring development of analytic tools for evaluation of vehicle performance. Initially this activity took the form of studies of single factors affecting performance and then as data accumulated on many areas, the focus turned to development of comprehensive off-road performance evaluation. This work culminated in the development of the NATO Reference Mobility Model (NRMM)[4].

The objective of these analytic efforts was development of means to assess vehicle performance without the need to build prototypes and test every design. Parametric studies can aid the vehicle designer or assessor in judging the effect of changes in vehicle configuration

on overall performance. The comprehensive analyses also identify areas where the underlying base of technical data is weak and so guide further studies.

The problem addressed here is that most of the Army's analytic efforts in the last two decades was focused on the need to assess performance of vehicle configurations not markedly different from those fielded in the recent past. Although the CCRV demonstrated significant gains in several performance areas, few of the mathematical models adequately represent the factors which make that vehicle different from the single unit base vehicle. In fact, the areas in which the performance gains demonstrated were most striking, such as obstacle negotiations, are those in which the existing methodology is weakest.

ARTICULATION AND MOBILITY MODELS

When the comprehensive mobility model, then called AMC-74, which eventually became the NRMM was designed, it was decided to address two aspects of cross-country travel in stand alone preprocessor modules. For the NRMM analysis the vehicle is subjected to the full range of terrain conditions found in the area under study and the vehicle's capabilities for this range is made a part of the vehicle characteristics for the cross-country speed calculation. The two aspects of vehicle performance so addressed are "ride", the transmission of shock and vibration to the driver crossing rough terrain, and obstacle negotiation. These simulations may, of course, also be used individually to examine these aspects of vehicle performance.

These two areas addressed by the stand-alone modules of the mobility model are ones in which articulation has been shown to provide improved performance. A computer simulation of shock and vibration transmission, known as VEHDYN and developed by WES, had been under development for several years when the AMC-74 Mobility Model was

designed and was adopted as the Ride Dynamics Module. Because of interest in articulation at WES and the well advanced state of this simulation, provision for description of articulated tracked vehicles is included in the current version and this is deemed to be adequate to meet the needs of the NSRDC/Marine Corps in assessing ride performance of articulated tracked vehicle concepts.

Before focusing on the obstacle negotiation problem and the closely related gap crossing problem, we should observe that the remainder of the Mobility Model does not have provision for assessing differences in performance of articulated tracked vehicles except for the differences determined by the preprocessors. Many of the relationships used in the Areal and Road Modules are empirically derived from test results amassed during recent decades. Motion resistance is based on one-pass vehicle cone index. In truth, the second unit of an articulated pair is making a second pass but hardly any data exists on the change in resistance to motion on the second pass. Reduction of speed due to maneuvering around obstacles and vegetation is based on observations of conventional skid steered vehicles and these empirical relations may not reflect properly the maneuverability of a vehicle which, although relatively long, could be steered by yaw articulation. Steering by articulation is also not described in the Road Module wherein additional resistance around curves is calculated from an empirical relation based on tests of skid steered conventional tracked vehicles.

While these concerns in proper evaluation of performance of articulated vehicles are of importance, they are not felt to be of highest priority. The change in resistance to motion of the second unit should be monitored in future testing of articulated vehicles and once its magnitude is established, the need for better relationships can be established. The differences in steering are being studied elsewhere [6, 7]. The area on which we now focus is obstacle negotiation.

Here we note that significant differences in performance due to articulation have been observed in field tests while the analytic evaluation methodology is weakest.

OBSTACLE CROSSING MODULE OF THE MOBILITY MODEL

The preprocessor module to assess ability of a vehicle to crawl over an obstacle turned out, in itself, to be an obstacle in the development of the comprehensive AMC-74 Mobility Model. The initial attempt at analysis of the problem was deemed a failure due to assumptions of linearity which were unwarranted and to difficulties in describing tracked vehicles. The experience with this attempt lead to the assumptions embodied in the program which is presently in use [4, Vol. II]. This is a two dimensional simulation of a non-compliant vehicle placed in static equilibrium at a sequence of locations across a dry non-compliant stylized obstacle. Furthermore, the vehicle configurations permitted are restricted to those which do not lead to static indeterminancy. The underlying solution technique is numerical solution of systems of non-linear algebraic equations.

The restrictions imposed on vehicle configurations present the greatest problem when dealing with tracked vehicles. For a single unit, the requirement is that the vehicle be supported at two points. Each support location may represent either a single axle or a bogie or walking beam pair of axles. Reasonable simulation of the motions actually observed with a tracked vehicle is achieved by replacing the actual suspension system by a pair of appropriately located walking beams with very large wheels. Limits are placed on the angular rotation of the walking beam arms to assure that the psuedo wheels are approximately where the track should be. These large wheels are used only in the geometric calculations; for the force and moment balance the walking beams are equipped with wheels of the size of the road wheels. Finally,

the presence of the sprocket and idler is taken into account and, when appropriate, the support of the vehicle is transferred from one of the walking beams onto the proper sprocket/idler.

The basic structure of this simulation also imposes restrictions on the additional units possible. These must be trailers with one support (single axle or walking beam pair) free to pitch around the trailer hitch. While there is in principle no limit to the number of such trailers, the present computer code provides for only one trailer.

Two ways to simulate a two unit tracked vehicle are available within the constraints of the structure of the Obstacle Crossing Module. The first is to treat the second unit as being supported by a single walking beam suspension with wheel size and location chosen so that the wheel envelope matches that of the tracks. The rear sprocket or idler can be accounted for with transfer of support when appropriate as in the present simulation. This approach requires geometric simulation with very large wheels, which is certainly unrealistic, and freedom of the second unit to pitch around the walking beam arm which introduces errors into the force/moment balance equations that could be large. More importantly, simulating the motion with a single walking beam precludes the re-creation of the track yielding, especially when the end road wheels contact the obstacle such as is obtained with the pair of walking beams used on the first vehicle. Thus, a realistic time history of attitude of the second vehicle crawling over an obstacle cannot be produced. Finally, and most importantly, provision for control of intervehicle pitch angle is not possible using this approach.

The second approach to analysis of articulated tracked vehicles is representation of the second unit's suspension with a pair of walking beams as is done for a single vehicle. Unfortunately,

the configuration which is successful for representation of a single unit -- a fixed relation of the center of gravity and the two support points -- is not possible for the second unit without producing a statically indeterminant system. To avoid the indeterminant case, the second unit could be simulated as a pair of trailers, each supported by a walking beam suspension. The first trailer would be hitched to the first unit and the second trailer would be hitched to the first trailer. Whereas the first approach suggested has too much rigidity, this solution has too little. The freedom of the second trailer to swing around its hitch point to the first eliminates the fixed relation of the center of gravity and the suspension supports. This broken back attack on modeling the second unit can introduce serious errors into the force/moment balance equations and even distort the prediction of geometric clearance/ interference. Finally, as in the first approach outlined, control of intervehicle angle cannot be simulated.

In conclusion, it should be recalled that the Obstacle Crossing Module was designed as a simulation to assess the capabilities of conventional vehicles with sufficient accuracy for its use as a preprocessor for the Areal Module of a comprehensive mobility model (now existing as NRMM). The inherent assumptions of the approach restrict the range of appropriate vehicle configurations. The simulation of a tracked vehicle is already a compromise with reality; based on the above discussion, extension of the present Obstacle Crossing Module of the NRMM to articulated tracked vehicles is not recommended.

OTHER STATICS MODELS

An analysis based on examination of a sequence of static equilibria is possible without all the restrictions of the Obstacle Crossing Module. At present, Stevens is developing a "gap crossing

model" under the sponsorship of the U. S. Army Corps of Engineers. This effort addresses negotiation of linear features which may be water covered (such as streams). This effort is intended to be a generalization of the Obstacle Crossing Module. However, the concern with stream crossing precludes the separation of vehicle/ terrain geometry and the force balance which is part of the design of the Obstacle Module. This also can produce a statically indeterminant system. To avoid this, an optimization scheme rather than solution of algebraic equations as the underlying technique is being considered for the gap crossing model. This is more promising as a technique for analysis of performance of articulated tracked vehicles. Some of the compromises in description of tracked vehicles are no longer required as the statically indeterminant situation can be handled. However, another problem which has surfaced in analyses using the Obstacle Module will still exist.

The solution of a system of non-algebraic equation is equivalent to optimization of a function of several variables. [A necessary condition of a minimum of a function is that its partial derivatives all be zero. On the other hand when a set of functions are all zero, the sum of their squares is minimized.] Techniques for the numerical solution of these equivalent problems are troublesome. The computation time appears to be an exponential function of the degree (the number of independent variables). Furthermore, as the degree increases, the methods require better initial approximations to the solution. This convergence problem has been noted with the Obstacle Module even for relatively simple vehicle and much time went into automating the selection of initial approximations in critical conditions. Even so, problems remain and furthermore the computation costs are significant. The optimization technique of the gap crossing model shares some of these problems and the increase of degree associated with articulated tracked vehicles is likely to make this approach untenable.

DYNAMIC ANALYSIS

A dynamic analysis of obstacle negotiation is inherently attractive since observation of field trials suggests that dynamic effects are significant in successful negotiation of difficult situations.

In addition, the underlying mathematical techniques in dynamic analysis, numerical solution of differential equations, has seen much progress in the last twenty years [8]. Robust algorithms are available for a wide variety of problems and improvements in efficiency have resulted from developments both in computer hardware and software. This aspect of improvment in our technology makes this type of analysis attractive in the 1980's. Dynamic analyses were often avoided in the past due to their cost. It is of course pointless to develop a simulation of a situation if one can't afford to run the simulation. The gains in computational efficiency in the last decade make it appropriate to consider the dynamic approach.

Dynamic analysis of mechanical systems is a wide spread concern. In the 1960's development of general purpose computer programs commenced at several locations. General purpose computer codes for analysis of large scale, non-linear, constrained, rigid body mechanical systems appeared in the early 1970's. In these first generation codes, program generality (the ease of handling a wide variety of systems) is traded off for program efficiency. Effort in the following decade produced codes which are intended to maximize program efficiency and generality. An example of the current state of general purpose dynamic analysis codes is the Dynamic Analysis and Design System (DADS) [9]. DADS is the result of combining a system with great generality and ease of use which was less efficient than other general purpose codes with recently developed computational techniques to achieve a code markedly better than those of the

previous decade. A brief description of the first generation general purpose codes together with presentation of the developments implemented in DADS is contained in Reference 9.

DADS is particularly attractive as a basis model for analysis of articulated tracked vehicles negotiating obstacles because this problem has indeed been addressed [10]. The particular problem dealt with was analysis of the system for control of intervehicle pitch installed on the Army's coupled M-113 test bed [3] while negotiating a step or crossing a trench. Vehicle and road wheel motions predicted by the simulation were much like those observed in the field tests of the coupled M-113's at computer costs judged reasonable by the sponsor of the study.

In this study of the coupled M-113 test vehicles, the objective was analysis of the effect of different modes of operation of the control system. Information which would be required for other types of performance analysis, such as would be desired by the Marine Corps was not needed and so not addressed. In addition, simplifications to the terrain-vehicle system were introduced which were judged to be secondary effects for the matters concerned. However, for assessment of vehicle performance some of these effects should be included. In particular, the forces at the track-ground interfaces were treated as a simple uniform frictional force. More detailed effects of terrain (motion resistance, traction vs. slip, buoyancy, etc.) should be worked into the analysis for performance prediction.

The relative ease of inclusion of control of intervehicle pitch together with the ability to handle a wide variety of vehicle configurations in a dynamic analysis makes this approach preferrable to statics based analyses for the complicated system which an articulated tracked vehicle represents. The possiblity of extending the work

already developed under the sponsorship of the U. S. Army's Tank-Automotive Command is a special reason to select DADS as a basis for analysis of performance of such systems to the extent that this is needed by the Marine Corps.

CONCLUSIONS

- The simplistic approach of the Obstacle Crossing Module should not be extended to articulated tracked vehicles.
- A model based on static equilibrium, while feasible, is less appropriate than a dynamic simulation.
- The methodology should address control of intervehicle pitch.
- A general purpose dynamic simulation should be used for the analysis.
- The Dynamic Analysis and Design System (DADS) is well suited for the purpose.

RECOMMENDATIONS

- Apply the DADS Program to U. S. Marine Corps Articulated Tracked Concepts to represent mobility factors critical to performance prediction

  1. Expand the track-ground interface submodel to include traction-slip relationships and motion resistance.
  2. Include buoyancy effects.
  3. Determine the vehicle, control system, and terrain description needed.
  4. Select and organize the output appropriate for performance prediction.

- Describe and specify the mechanical and control system details to simulate the vehicles under concern.

- Predict obstacle and gap negotiation performance of vehicles being tested by WES and validate/tune the analysis.

- Apply the validated prediction technique to breadboard designs.

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